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AN EVALUATION OF MECHANICAL AND FORMABILITY PARAMETERS OF ALUMINIUM BASED POLYPROPYLENE SANDWICH MATERIALS

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ABSTRACT

Sandwich materials have been gaining acceptance in variety of applications ranging from building materials and toys to automobile, locomotives and aircrafts. In this research paper, a study is carried out on sandwich sheets comprising of AA5182 as the skin material, polypropylene as the reinforcement with orientation of 0^o, 45^o and 90^o with respect to rolling direction and epoxy resin as the binder element. The said sandwich sheets were fabricated using hand layup technique because of its ease and effectiveness to produce bulk materials. The resulting materials had the configuration of 2/1 i.e., AA/PP/AA. Mechanical examinations were carried out to determine its tensile strength, impact strength, flexural strength and Erichsen cupping index. Microscopic tests on the fractured surfaces obtained after the above mentioned examinations were taken using Scanning Electron Microscope. The experimental results found to have good mechanical properties for the material especially on the sandwich sheet having 90^o orientation of the polypropylene against the rolling direction. Notable enhancement in the mechanical property of the sandwich sheet include good load bearing capabilities during flexural tests, decent Erichsen cupping index and resistance to low velocity impact loads.

KEYWORDS: AA/PP/AA Sandwich Sheets, 0^o, 45^o and 90^o Rolling Direction, Mechanical Properties, Forming Parameters & Scanning Electron Microscopy (SEM)

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Original Article

1. INTRODUCTION

Due to the gradual requirement of the energy sources which have been developed in the past few years led to many issues. In the recent years, many metal/plastic commonly thermoplastic as polypropylene core in between laminated sandwich sheets have produced considerable interests as a prospective light weight of the structural parts. This light weight property can be taken advantage by the automobile industry [1-5].

The mechanical behavior is analyzed by calculating the yield function for roll bonding. With less strain hardening exponent, there is an increase in strain sensitivity. Increase in formability of the material was found to be on the account of larger thickness [6]. Polypropylene was selected for its low density, costs and high recyclability. With flexural properties in mind, the AA5182/PP/AA5182 sandwich material was manufactured with two aluminium sheets with a thermoplastic core. With a pre-rolled polypropylene, the sheet was done by rolling two 5182 aluminium sheets. EVA was used as adhesives for the sandwich material. For better bonding results,

a mechanical roller was used for the high force required [7-10].

Sandwich composites comprises a stabilizing core of filling and between them two outer metal sheets (steel, aluminium or any other). The core and skin together create a lightweight structural panel material [8-11]. The metal sheets are bonded to the core with specialized EVS. The materials have many advantages such as low weight and higher shear stiffness to weight ratio than an equivalent beam. The high stiffness of the face-sheet leads to the overall high bending stiffness to weight ratio for the composite. Overall, the sandwich arrangement allows for excellent mechanical performance at nominal weight [12-15]. With several processes available, cold and hot working process is chosen. In cold working process, there is no external heat used, while in hot working process external heat is supplied to the material. Mostly aluminum is used for manufacturing sandwich composite material due to its low weight and easy deformation upon applying of load. Depending upon the required number of layers, the usage of sheets and reinforcement materials are increased. In general, it is a tri-layered composite used for the research purpose [16-21].

With top layer generally selected with characteristically high stiffness, the core has to exhibit high shearing and compressing strength [22-26]. It is imperative for the compatibility of adhesive with materials to be high, for better results [27-29]. The material has better stiffness to weight ratio than a simple monolithic material [30-36]. It has better fire retardant property, corrosion resistant. In the present study, the AA 5182 aluminium alloy sandwich sheets that has been fabricated using press joining process and to study the formability evaluations. Furthermore, using Scanning Electron Microscopy, the effects of the material fracture were found and of the material properties on stretch forming were studied.

2. MATERIALS USED

2.1. Aluminium Alloy (AA5182)

With good preventive measures like corrosion resistance and bio resistance, Aluminium was chosen for this study. The aluminium is one of the most malleable and ductile material. An important criteria for the selection of the aluminium alloy (AA 5182) for the sandwich sheet is its ultimate tensile strength and flexural rigidity [20]. The table 1 shows the chemical composition of aluminium 5182 alloy sheet.

Table 1: Chemical Composition of AA5182

AA5182	Mg	Cr	Si	Fe	Cu	Mn	Ti	Al
%	4.51	0.02	0.08	0.18	0.005	0.34	0.02	Balanced

Aluminium alloys has a high performance application in aerospace industries because of their low weight, which reduces fuel consumption. However, pure aluminium metal is too soft a material, with low tensile strength which is a disadvantage when it comes to manufacturing of airplanes and helicopters. The mechanical properties AA5182 are shown in Table 2.

Table 2: Properties of AA5182 Sheet Metal

UTS tensile strength	421.0	MPa
Yield strength	393	MPa
Density	2800	kg/m^3
Elongation	10.0	%
Brinell hardness	58	HRB
Thermal conductivity	123	W/mK

2.2. Polypropylene

The core material, polypropylene, due to its low density, less costs and relative high refractoriness. The polypropylene plastic material has low density, join ability, recyclability, and cost saving of the material. With weight, formability, and dent resistance in consideration, the thickness of aluminium was determined.

2.3. Manufacturing Process

In the current investigation, the sandwich material was procured from A3 Composites Polycasa in the name of HYLITE. The thickness of 0.5 mm are chosen on 5182 aluminium outer layer of sheets and on the polypropylene core, respectively [21]. Based on literature review, it is found that the sandwich materials has was manufacturing used by a rolling process of two alloy skins. The required pressing force is accommodated with a mechanical roller. Firstly, the AA5182material are to be cleaned to remove dirt and unwanted materials. A better bonding between the metal sheets and polypropylene sheet is achieved with the subjugation of activation temperature of 140°C. The first 60 second in the stationary conventional oven is the dwell time, and the next 45 seconds is put in a cooler at nominal temperature. The diagram of the rolling process is shown in Figure 1.

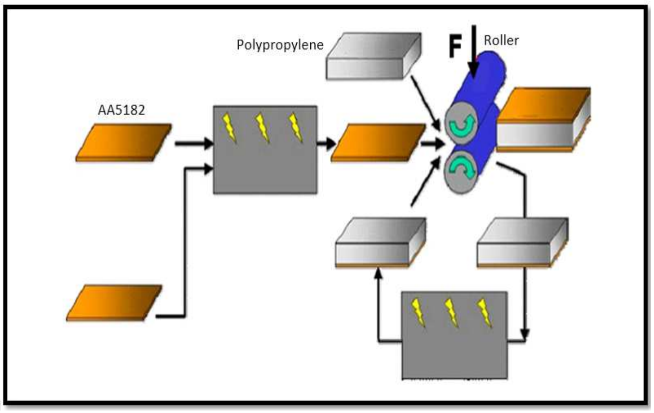


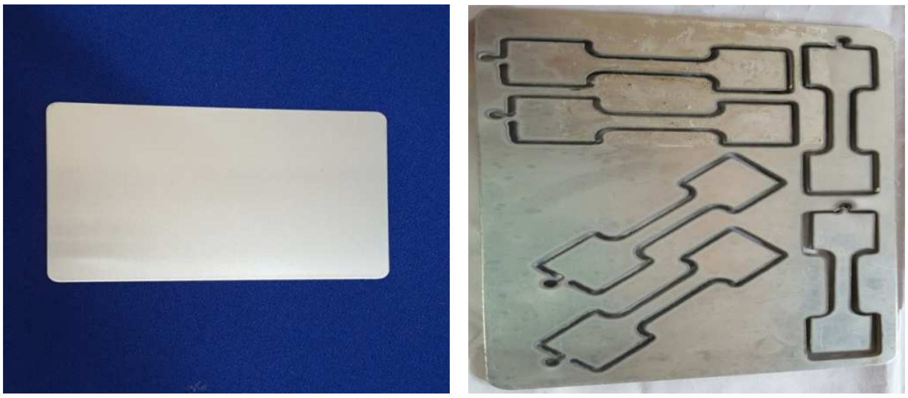
Figure 1: Schematic Diagram of Roll Bonding Process of Sandwich Material

The roll bonded sandwich sheet was dimensioned according to the ASTM standards & IS standards before cutting of the test specimen. The test specimens were cut using water jet cutting was then used to obtain the desired experimental geometries [12,37]. Since it is the most accurate type of machining process and does not disturb the core material of the sandwich sheet.

3. EXPERIMENTAL PROCEDURE

3.1. Specimen Preparation

Water jet cutting is commonly used during fabrication of many products. The materials being cut are sensitive or possess an intricate shape of cut. This is achieved with the help of specialized 3D-software or 2D-software such as auto-cad. One advantage is the ability to cut material without no heat-affected zone. This method is also used when fabrication flaw like pores and deboning and delamination should not be carried any further, moreover a clear surface finish is required. Figure 2 shows the fabricated samples.



(a) (b)

Figure 2: (a) Test Sample Before Machining and (b) After Machining

3.2. Macro Imaging of the Sandwich Material

The macro imaging is a technique which is used to relate the interior defects of the sandwich sheet metal after fabrication and before mechanical testing. This image of the specimen was been seen under the optical microscope. The images showed the various Interior defects of the fabricated material. It was noted that the polypropylene core material had long continues minute crack line along its structure throughout the specimen. It was also noted that the aluminum skin layer had short discontinues cracks. It may be Interpreted due to the few errors in the fabrication of the sandwich sheet metal. The macro imaging technique also helps to understand the propagation of interior and surface defects of the test specimen while undergoing various mechanical testing in future. The Figure 3 represents the image obtained from the macro image testing. The top layer of the image shows the aluminium 5182 as the skin layer and the core layer of polypropylene material.

Figure 3: Represent the Macro Image of the Fabricated AA5182/PP/AA5182 Sandwich Metal

3.3. Parameter Selection

The AA/PP/AA sandwich sheets of three different rolling dimension of the specimen were fabricated using the variable 0°, 45°, 90° represent the planar anisotropy (ΔR). In determination of the normal anisotropy, the lines helped with process over the roll bonded sandwich with ASTM standards as shown in Figure 4 [4]. The sandwich specimens were segregated with thickness 2mm along three different angles namely 0°, 45° and 90° to the sheet rolling directions of the sandwich sheet.

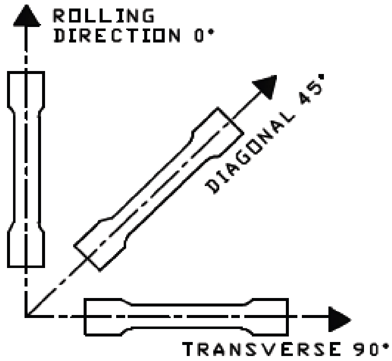


Figure 4: Tensile Specimen Orientation for Determining 'R' Value [4]

The examination of the material is used with multiple test for bonding and mechanical parameters such as hardness tensile, shear properties, and impact. With the Erichsen Cupping Index (IE), stretch formation is realized, which is the height of the cup is taken as reference while comparing the sandwich samples.

4. MECHANICAL TESTS

4.1. Tensile Test

Using specimen of 12.5mm wide and a gauge length of 50mmfrom specimen, the before and after fracture of the specimen as shown in Figure 6. The test were conducted at normal atmospheric conditions and the measurements to identify strain-hardening exponent, the yield strength, and plastic strain ratio are observed accurately using extensometer.

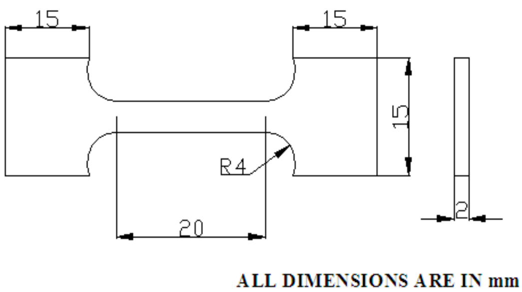
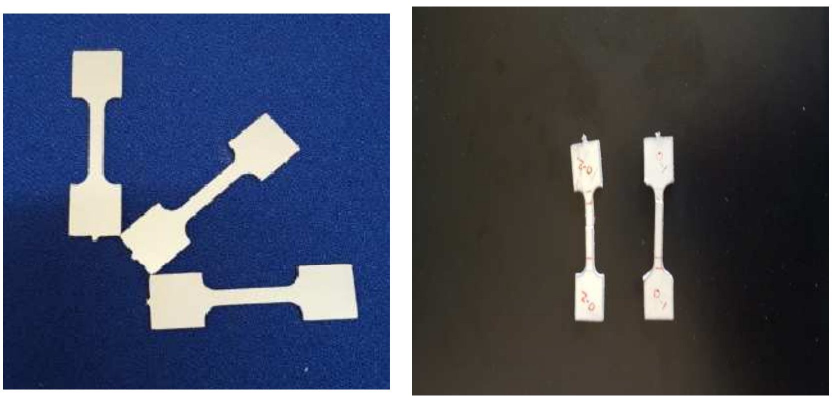


Figure 5: Tensile Test Specimen as per ASTM E8

UTM was employed by applying a constant load of 400kN. With head speed of 3mm/min, tests were conducted. The fracture found in the aluminium skin, then in the polypropylene core.



(a) **(b)**

Figure 6: Tensile Test Specimen (a) Before Testing and (b) After Testing

The true stress was expressed as,

$$\sigma = k\varepsilon^n \quad (1)$$

This is equation k is the Strength co-efficient, an important constant for fabrication, σ is true stress, force over area, of sandwich sheet, ε is the true strain of sandwich sheet and n is the Strain hardening exponent respectively.

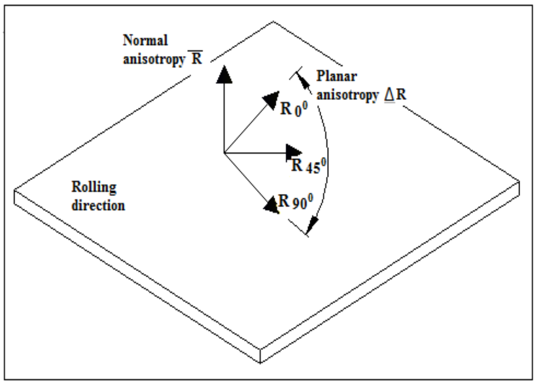


Figure 7: Axes Used in Defining Normal and Planar Anisotropy

It was found that sandwich's tensile strength varies different orientation of planar anisotropy. The strain was experimentally found during the study[6].

4.2. Flexural Test

The test is done with the sandwich sheet subjected to 3 point bending tests. Then, flexural strength was determined following ASTM D790 standards. An UTM was used for the experiment by applying a force at a rate of 3mm/min. For the short length sandwich sheets, 100mm length,12mm width and 2mm thick is chosen as per this standard was used for best result. The Schematic or graphical representation of the flexural test as per standard is shown in Figures 8 & 9.

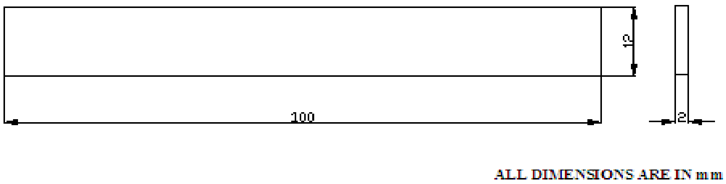
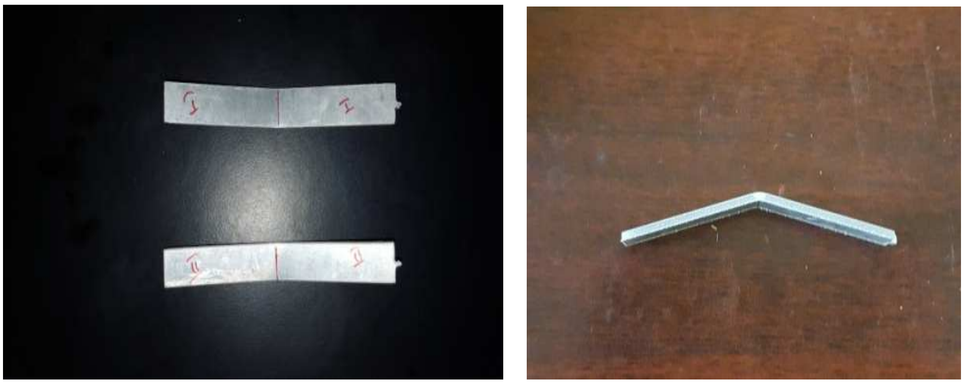


Figure 8: Flexural Test Specimen



(a) **(b)**

Figure 9: Preparing the Test Samples (a) Before Testing and (b) After Testing

4.3. Izod Test

The sample was tested with high accuracy Izod impact testing to withstand the sudden shock loads in accordance with ASTM standards. A 65.5mm for length, 12.7mm for width and angle 45^0as notch ASTM D256 standard. The Figure 10 shows the izod impact test specimen as per ASTM256.

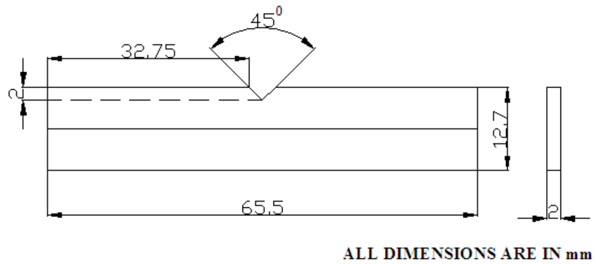
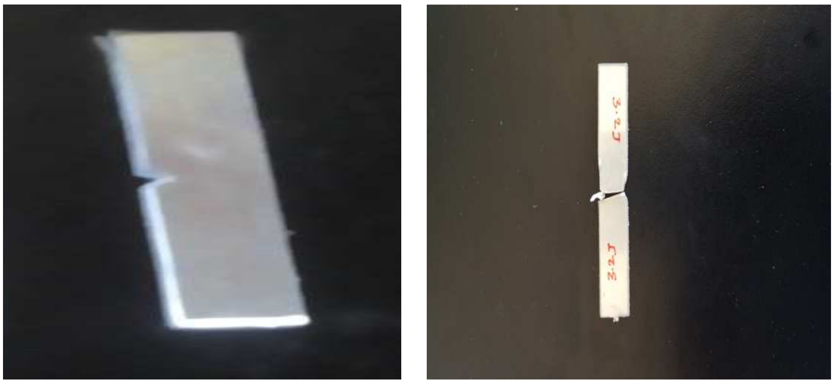


Figure 10: Izod Impact Test Specimen as Per ASTM D256

The Impact testing machine comprises of a striker upon release kinetic energy of3.5m/s is given off. The Figure 11 shows the test samples before and after testing.



(a) (b)
Figure 11: Impact Test Samples (a) Before Testing and (b) After Testing

4.4. Erichsen Cupping Test

The test specimen was tested to determine formability of the specimen with width and length of 90×90mm, as IS 10175 standards suggests. The cupping test in illustrated in Figure 12.

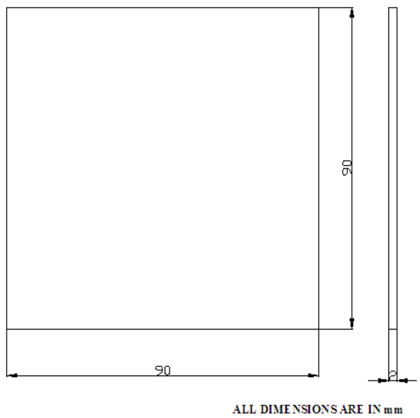
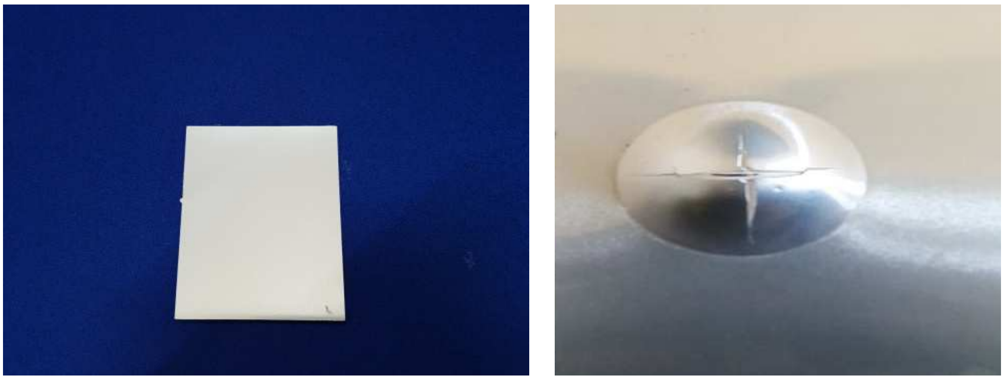


Figure 12: Erichsen Cupping Test Specimen as Per IS 10175

The maximum blanking force 200 KN and maximum drawing force 100 KN are applied, followed as per IS standards. This is done for the best results of the experimentation. A punch is pushed with hydraulics into the sheet metal, till a crack appears. The Figure 13 shows the cupping samples before and after testing.



(a) **(b)**

Figure 13: Erichsen Cupping Test Samples (a) Before Testing and (b) After Testing

5. RESULTS AND DISCUSSIONS

Mechanical properties is a technique with the help of which one can easily determine the formability parameters by simple performing numerous Mechanical tests (tensile, flexural, izod impact, erichsen cupping test. In this chapter, the mechanical properties are determined by calculation from the given data also analyzed the fracture studies that is obtained over testing. This extensively study helps to compare and find out the differences between the experimental and calculated values.

5.1. Tensile Properties

The test specimen were cut and then bonded into sandwiches. According to few investigates [8], the true stress-strain curves, an important feature to consider when considering this test, can be predicted with the aluminium skin and the polypropylene core with rule of mixture in mind.

Table 3: Represents the Mechanical Properties and Formability Parameters of AA5182/PP/AA5182

Orientation Relative to Rolling Direction	AA5182/PP/AA5182								
	n	K (Mpa)	σy (Mpa)	σu (Mpa)	Elongation %	R	nR	ΔR	$\overline{R}$
0^0	0.8082	0.9990	91.23	97.5	7.1	0.581	0.469	0.2987	0.4459
45^0	0.7947	0.7874	88.56	94.5	8.97	0.2966	0.235		
90^0	0.7972	0.9999	93.0	98	6.9	0.6097	0.486		

From the experimental results, a graph has been plotted that illustrates the stress-curves from the rule of mixture is shown in Figure 13. The tensile strengths of the 45^0 orientation is 88.5 of yield strength and 94.5 MPa of ultimate strength is lowest compare to the 0^0, 90^0. With examination of the various properties of sheets in table 3, the tensile elongation of the 45^0 is 8.97 % is increase then the 0^0 degree orientation is found. Specimens was prepared with ASTM standard, specifically ASTM E8/E8M, in consideration. The stress-curve of the sandwich sheet is illustrated below. Tensile strengths of the 90^0 orientation were found 93.0 of yield strength and 98.0 Mpa of ultimate strength.

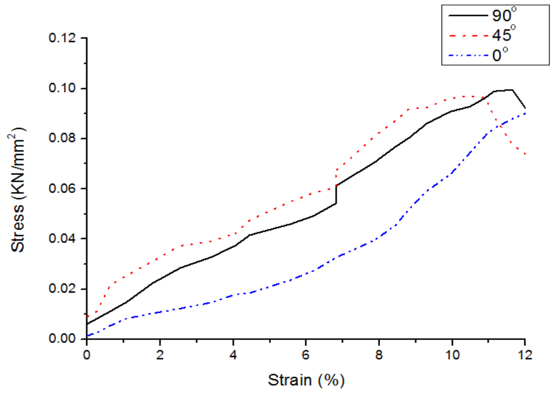
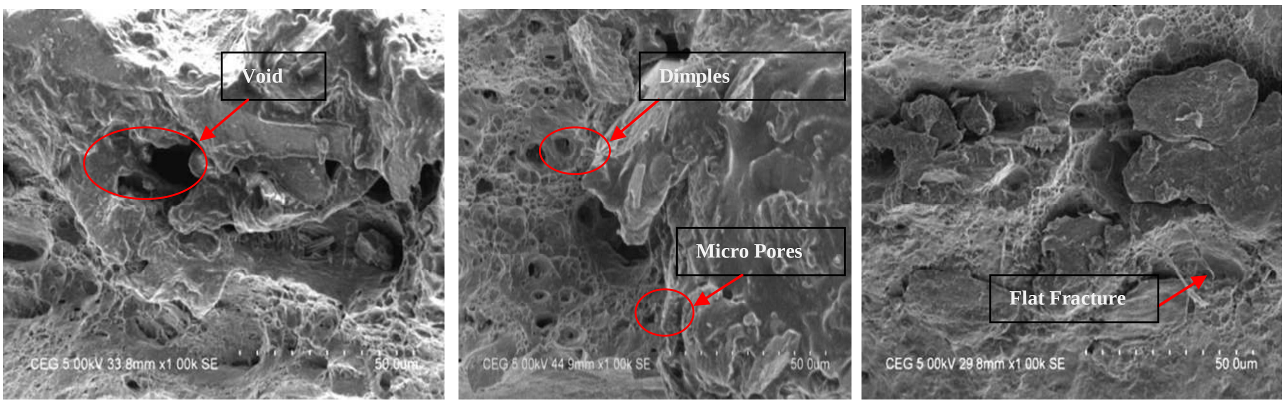


Figure 14: Stress Strain Curves of Cross - Head in Tensile Test of Different Rolling Sequence



(a) 0^0 of the Tensile Specimen De-Bonding Region

(b) SEM Image of 45 Degree of the Polypropylene Centre Core Region

(c) 90 Degree of the Core Interface Fracture Region between the Aluminum Skin and Polypropylene Core

Figure 15: SEM Image of Sandwich Sheet after Flexural Test

Figure 15 shows the SEM Fractography studies of the sandwich specimen. The Fracture surface were indicates from the $0^0$of the debonding core region shows a typical air void when fractured illustrated in Figure 15 (a). Fractography found in 45^0 of the sample polypropylene center core region as shown circular dimple fracture mode in Figure 15 (b), which is usually on the fractured surfaces of the core. Figure 15 (c) shows a SEM of90^0 tensile sample found close the interface on the flat fracture between skin and core. Fractography confirmations fracture at the interfacial structure and core short of debonding, which means it is tough enough to escape premature debonding. With strong influences at the extreme level, it is found that the fracture takes place in the aluminum skin then in the polypropylene core interface. Additionally, the tensile elongation of the sandwich is relatively better than Aluminum.

5.2. Flexural Bending Test of Sandwich Sheets

In present work to study the flexural properties, maximum displacement with break load flexural stiffness and modulus of the test specimen, the many characteristic properties are explored with an experimental approach. The sandwich material was procured from the company and directly given for further testing with ASTM standards. The failure modes of sandwich sheets has been characterized. According to literature [4], the load versus displacement curves of the specimen measured from flexural test, according to the rule of mixture.

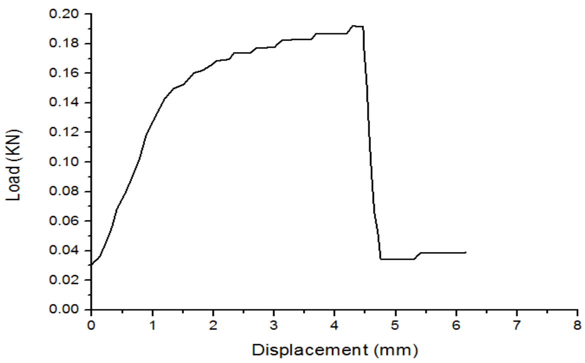


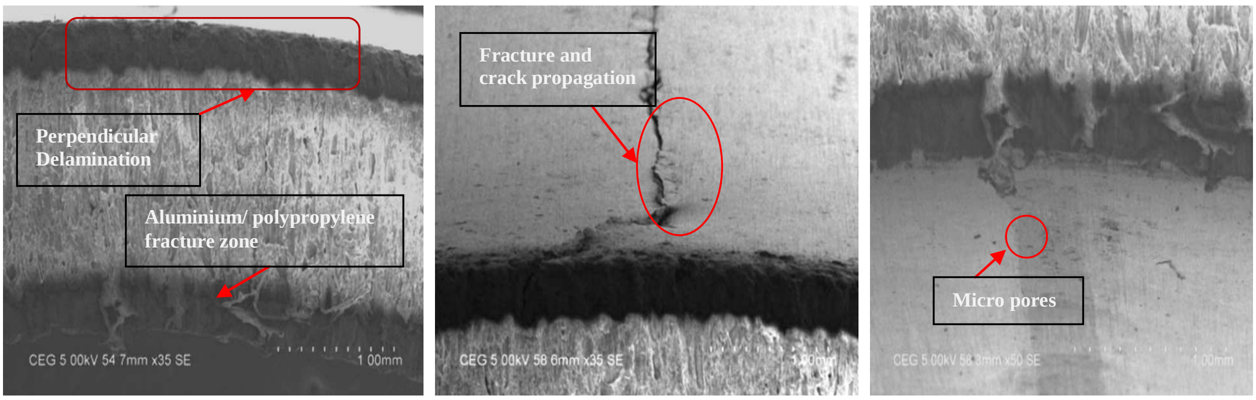
Figure 16: Represents the Graphical Image of Flexural Test Specimen under Load vs. Displacement

Figure 16 Shows load-mid span deflection and the Table 4. The test subject is found to increase linearly with respect to displacement and sharp reduction when fracture occurs. With the decrease in breakage flexural strength, the graph above illustrates that there is an increase in loadup to ultimate flexural stress and then decreases with breakage flexural strength,

Table 4: Predicted and Calculated the Flexural Strength of the Sandwich Sheets, (AA5182/PP/AA5182)

Flexural Specimen	P (kN)	D (mm)	S_f (MPa)	σ_f (MPa)	E (MPa)
Specimen 1	0.205	6.33	32.385	605.31	218.085
Specimen 2	0.210	6.4	32.812	620.07	217.972

With the increase of thickness in polypropylene, the load and flexural modulus increased. The flexural modulus of the sandwich specimen is found that the value is 218.02 MPa. The graph illustrates decreasing gradient with polypropylene core towards to pull out from the flexural specimen. The deflection increases with linear relationships to ultimate failure. While conforming to the ASTM standards, the specimen has a width of 30 mm and length 150 mm.



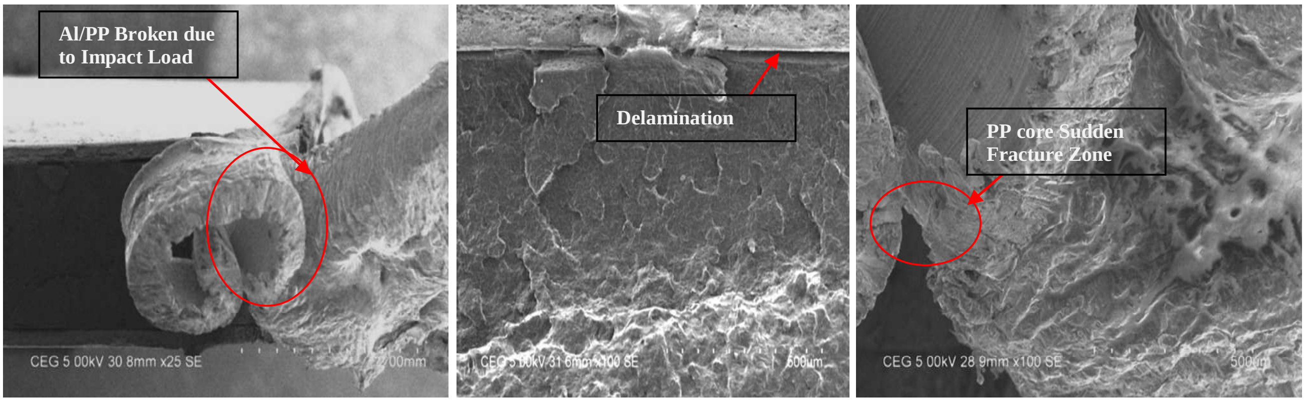
(a) Arrangement of Aluminium/PP Delamination Perpendicular Zone **(b) SEM Image of Sandwich Composite Bending Center Fracture Specimen** **(c) Overlapping Magnified Portion that Displays Micro Pore and Bending Fracture Zone**

Figure 17: SEM Image of Sandwich Sheet after Flexural Test

Figure 17 (a) shows that the arrangement of polypropylene in the sandwich sheet which obtained one layer of aluminium perpendicular to the other layer of the polypropylene. Figure 17 (b) illustrates microstructure view of a flexural fractured specimen. Internal structure phase, an important feature to be considered, is established with cross-sectional of

the applied load. There are minimal air gaps due to uniform load applied. The initial crack propagates through the polypropylene core rather than the other sandwich structures and causes failure [4]. Flexural strength values also indicate that there is very minimal stress to the aluminium and hence actual low values. Figure 17(c) shows the aluminium/ polypropylene are found to be unbroken and shown micro pores on the matrix zone which recommends there is good wetting of the aluminium by the polypropylene matrix. Adequate interfacial structure ensures good bending cause of the fracture.

5.3. Izod Impact Test of Sandwich Sheets



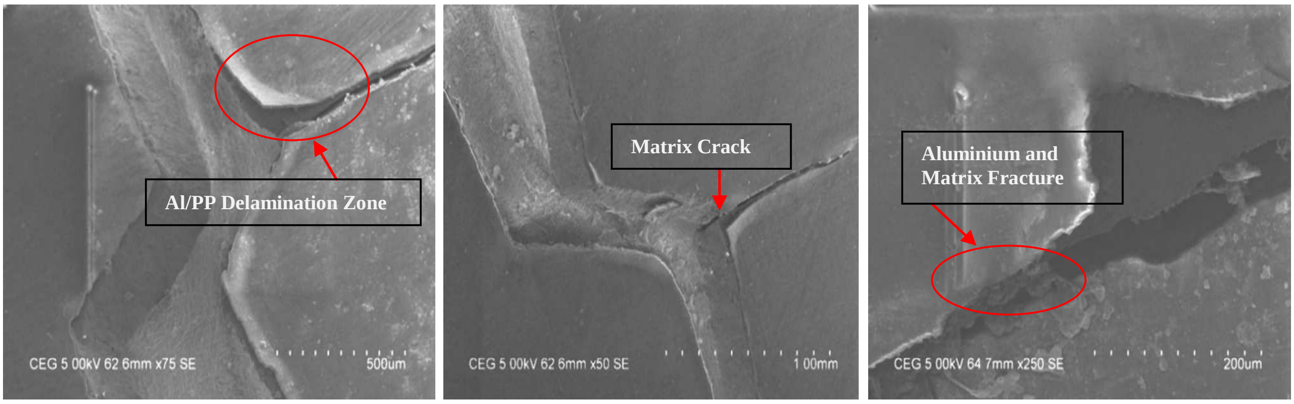
(a) Aluminium/PP Sudden Broken Impact Load on the Ductile Fracture **(b) Presence of Delamination in the Impact Sample** **(c) PP Core Fracture Zone**

Figure 18: SEM Image of Sandwich Sheet after Impact Test

The energy absorbed by specimen is 3.2 Joules, found out by the impact test with applying a sudden force. It is found that AA5182/polypropylene sandwich composite. Figure 18 (a), (b) and (c) shows the point of fracture surface. Figure 18(a) visibly shows the complete cracking and ductile failure of the Aluminium and polypropylene core interface. Figure 18 (b) also gives initial delamination on the matrix zone. Figure 18(c) illustrates perpendicular preparation of fracture for obtaining strength. The sandwich failed with given sudden impact, while no trace of fatigue failure is observed. Furthermore owing to the polypropylene nature of the sandwich material, uniform distribution in the core is present.

5.4. Erichsen Cupping Test of Sandwich Sheets

The sandwich sheet's operation of forming, erichsen cupping number attained for aluminium sandwich material (AA5182/PP/AA5182), as can be seen in this sandwich specimen, was not delaminated after erichsen cupping as shown in Figure 18. The four trials taken from the aluminium sandwich specimen, the erichsen cupping numbers of four trials, the average cupping value 11.52. The results have a better formability and ductility nature in the fabricated specimen is acquired.



(a) Presence of Initial Ductile Fracture Delamination of the Specimen **(b) Matrix Crack and Aluminium Ductile Fracture** **(c) Uneven Matrix Crack and Ductile Fracture of and Specimen**

Figure 19. SEM Image of Sandwich Sheet after Erichsen Cupping Test

To characterize ductility fracture surface of erichsen cupping specimens, microscopic analysis magnified portion is found using SEM. shows the figure 18. It shows the Fractography image of sandwich sheet after cupping test. It is found from Figure 19. (a), (b) and (c), the failure of the slowly stretching samples which is loaded in the stretch forming specimen. The ductile damage on the aluminium skin mechanism in the aluminium/ polypropylene bonding laminates constitutes a very complex process. The presence of initial ductile fracture and delamination on aluminium sandwich sheet. Failure occurred with the following failure of cupping specimen, then polypropylene cracking, and finally polypropylene sandwich, delamination and cup fracture.

6. CONCLUSIONS

- The formability evaluations for aluminium sandwich were investigated. The tensile test was performed on the fabricated sandwich sheet and the following properties were determined: ultimate tensile strength, strain hardening index, strength coefficient and yield strength.
- The tensile test were performed on the cut specimen of 0◦, 45◦, 90◦ of the roll bonding direction. Along 90^0 rolling direction, better mechanical and formability characteristics can be formed
- The determination of strength, flexural tests was performed. Flexural test results show that the material could withstand a mechanical load of 0.19 Kn. The absorption of low impact given and transmits uniform load without failure.
- The Izod test results in the sandwich sheet as the capacity to withstand a load of 3.2 joules. So, the material has the nature to absorb a low velocity impact loads.
- Erichsen cupping test results showed that, the highest index value of sandwich sheet metal is 3.91. The specific gravity of the erichsen cupping test specimen was taken and the result showed that the 1.272 kg/m^3. Due to the formability and ductility, it is the better alternative for automobile applications. The erichsen cupping tests were performed in order to determine the Erichsen number. It was found that the erichsen number values obtained were in good agreement with formability.
- The micro-structural examination by Fractography analysis using SEM imaging is done. The results showed that the tensile test specimen with 45◦ rolling direction orientation had relatively lower surface fractures and

sub-surface flaws when compared to other orientation specimen. The Fractography images of flexural test showed various hair line fracture and micro pores due to the deboning of the specimen. The Izod impact test showed that fatigue strips and micro pores due to the low velocity impact loads. Erichsen cupping test showed delamination of the test specimen due to the fact of its low dent resistance.

- With cheap fabrication and high abundance, it can serve as a better candidate to the conventional sheet metal and further with research and development. Hence it can be concluded that the sandwich sheets are commercially viable and can be used for applications requiring greater easy to form components and such materials are open to research and development to make tailored components to suit a specific requirement and properties.

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